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# The mechanism behind the DOM effects on methylmercury photodegradation

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Methyl mercury ( $\text{CH}_3\text{Hg}^+$ ), a neurotoxin, is the most toxic form of mercury that occurs in natural waters [1–4]. It is a cause of concern because of increasing worldwide pollution by mercury in both water and atmosphere [3, 5].

Photodegradation of  $\text{CH}_3\text{Hg}^+$  is one of the main removal pathways from surface waters, and it has been shown to occur in the presence of dissolved organic matter (DOM) but not in ultra-pure water [2, 4]. Several mechanisms for the photodegradation of  $\text{CH}_3\text{Hg}^+$  have been proposed, including: (1) direct photodegradation of  $\text{CH}_3\text{Hg}$ –DOM

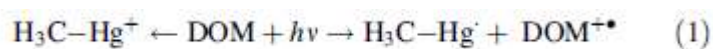
complexes via intramolecular electron transfer [4] and (2) indirect photodegradation of  $\text{CH}_3\text{Hg}$ –DOM by free radicals/ reactive oxygen species such as singlet oxygen ( $^1\text{O}_2$ ) and the hydroxyl radical ( $\text{HO}\cdot$ ) [1, 2, 6]. Studies show that the photo-Fenton reaction or the reactive oxygen species, including hydroxyl radical ( $\text{HO}\cdot$ ),  $^1\text{O}_2$ , triplet excited state of DOM ( $3\text{DOM}^*$ ), and hydrated electron ( $e_{\text{aq}}^-$ ), play a minor role in  $\text{CH}_3\text{Hg}^+$  photodegradation in aqueous media [3, 4, 6]. Interestingly, the photodegradation of  $\text{CH}_3\text{Hg}^+$  depends on the wavelength-specific incident photon flux, on DOM contents and salinity, but does not depend on nitrate photolysis [3]. It has been shown that rates of  $\text{CH}_3\text{Hg}^+$  photodegradation are decreased with increasing salinity and DOM contents [3]. Increasing DOM contents with the  $\text{CH}_3\text{Hg}^+$  aqueous media can act as a barrier to reach the incident light intensity toward the  $\text{CH}_3\text{Hg}^+$  component which could presumably decline the rates of  $\text{CH}_3\text{Hg}^+$  photodegradation. Several gaps still exist concerning the proposed photodegradation pathways, including two unresolved key questions: (1) how does DOM form bonds with  $\text{CH}_3\text{Hg}^+$ ? and (2) How is the newly formed complex excited upon irradiation? A couple of considerations may help in shedding some light over this issue and could provide scope for further research in the field.

The first issue is the formation of p-electron bonding systems between  $\text{CH}_3\text{Hg}^+$  [ $\text{Hg}^{1+} = 1s2s22p63s23p64s23d104p65s24d105p66s14f145d10$ ] and DOM ( $\text{CH}_3\text{Hg}$ –DOM), through electron donation from the functional groups of high molecular weight DOM to an empty sorbital of  $\text{CH}_3\text{Hg}^+$  (ligand-to-metal charge transfer) [7].

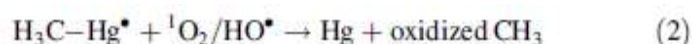
Note that the p-electron bonding system is not formed with low-molecular-weight DOM, because the formed complex would not be stable enough. The overall conditional complexation constants ( $K_0$  DOM) between  $\text{Hg}(\text{II})$  and DOM (extracted humic acids, fulvic acids and hydrophobic acids) show very strong interactions ( $K_0 \text{ DOM} = 1023.2 \pm 1.0 \text{ L/kg}$ ) at  $\text{Hg}/\text{DOM}$  ratios below approximately  $1 \text{ lg Hg/mg DOM}$ , which are indicative of mercury–thiol bonds [8].

Photodegradation of methylmercury can thus occur via a pathway that involves thiol complexation [2, 4]. In contrast, much weaker interactions ( $K_0 \text{ DOM} = 1010.7 \pm 1.0 \text{ L/kg}$ ) are observed at Hg/DOM ratios above approximately 10 lg Hg/mg DOM, coherently with Hg binding to oxygen functional groups [8]. The second issue is that p-electrons are loosely bound and they are highly susceptible to radiative excitation [7].

The ligand-to-metal charge transfer could be triggered by the photolysis of the complex  $\text{H}_3\text{C}-\text{Hg}^+ \leftarrow \text{DOM}$  (where the “ $\leftarrow$ ” indicates electron donation), which could take place as follows (Eq. (1)):



Oxidized DOM ( $\text{DOM}^{+\bullet}$ ) could undergo several processes. Interestingly, similar phenomena involving the charge-transfer photolysis of  $\text{Fe(III)}-\text{DOM}$  complexes ultimately cause DOM mineralization via decarboxylation [1]. The species  $\text{H}_3\text{C}-\text{Hg}^\bullet$  might, for instance, react with  $\text{HO}^\bullet$  and/or  $^1\text{O}_2$  [1, 2]. Oxidizing transients are expected to preferentially react with the methyl moiety of  $\text{H}_3\text{C}-\text{Hg}^\bullet$ , because the p-electron bonding system would provide an increased electron density on the methyl group and would lower the excitation energy of the carbon–mercury bond [9]. Such processes would lead to the demethylation of  $\text{H}_3\text{C}-\text{Hg}^\bullet$ , with the formation of elemental Hg and oxidation of the methyl group (Eq. (2)).



Note that the formation of  $\text{Hg}^{2+}$  from the reaction (Eq. (2)) would not occur, because irradiated Hg cannot release its outer electron from the s-orbital and also because of the high availability of hydrated electrons in waters under the light condition [7, 10].

The occurrence of inorganic compounds can also be important: for instance, increasing salinity can decrease the photodegradation of  $\text{CH}_3\text{Hg}^+$  by several processes [3], including: (1) the scavenging of  $\text{HO}^\bullet$  by bromide (the main  $\text{HO}^\bullet$  scavenger in seawater) [7, 10] and (2) the different speciation of the  $\text{CH}_3\text{Hg}^+$  cation in seawater compared to freshwater. In seawater, the formation of stable complexes/ion pairs with anions such as  $\text{Cl}^-$  and  $\text{Br}^-$  may hinder the formation of the photolabile species  $\text{H}_3\text{C}-\text{Hg}^+ \leftarrow \text{DOM}$ .

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